NSWCCD-61-TR-1999/04 Heat Treatment of Al 7075 for Ejection Seat Shear Wire.

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Heat Treatment of Al 7075 for Ejection Seat Shear Wire.

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Shear pins in ejection seats are required to have double shear breaking load values in the range of 46-51 lbs. over the life of the equipment. Aluminum 6061-T6 that was cold worked to increase the shear strength was initially used and performed well for many years. Current lots of Al 6061 could not duplicate the double shear breaking load values and so it was attempted to achieve the required double shear breaking load in the Al 7075 alloy with a stable microstructure. A variety of heat treatments were performed and tested for hardness and double shear breaking load. This report presents the resulting heat treatment curves and the correlation between hardness and double shear breaking load. The proper heat treatment for this application is identified as a solution treatment between 870 and 900 °F for 32 hours, aging at 225 °F for 8 hours and then further aging at 350 °F for 144 hours. This heat treatment was found to produce a double shear breaking load in the required range that is stable over time.

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CONTENTS

TABLES

FIGURES

ABSTRACT

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ADMINISTRATIVE INFORMATION

This work was conducted by the Materials Processing Branch, Code 612 of the Carderock Division of the Naval Surface Warfare Center (NSWCCD) and the PAD Branch (Code 5120H) of the Indian Head Division of the Naval Surface Warfare Center. This work was sponsored Hill AFB. The work was supervised by Dr. L. Aprigliano, Code 612, Carderock Division, Naval Surface Warfare Center.

INTRODUCTION

Aluminum wire specified to have double shear breaking load in the range of 46-51 lbs. at the finished diameter of 0.0285-0.0295 in. is used as a shear pin in an aircrew ejection device. This device, shown in Figure 1, is a man-rated item that must work correctly the first time, every time.

Aluminum 6061-T6, cold drawn from 0.032 in. diameter to the finished diameter in order to increase the shear strength, was initially used and performed well for many years. After drawing, the wire is cut (using a guillotine cutter) into short segments. The shorter lengths are referred to as a shear pins. As shown in Figure 1, the shear pin (Item 1) is inserted into a small diameter hole through the firing pin housing (Item 2) and into the firing pin (Item 3). This prevents the firing pin from sliding and striking the primer (Item 4). This configuration must withstand shock and vibration.

During initiation, gas pressure (from a gas generator, TLX line, or similar) is applied to the rear of the firing pin. For test purposes, nitrogen is used and is applied at 1100 psi and a rate of 10,000 psi/sec (approximate values). Pressures and rates from actual use exceed these values. The specification requires that the shear pin must rupture between 400 and 600 psi of air pressure. The assembly must also meet these criteria between the temperature ranges of –65°F and 165°F. It has been found that if the shear pin has the specified double shear breaking load, it will perform successfully in this proof test.

When shear pin rupture occurs, the firing pin is able to move forward with enough velocity to impact and initiate the primer, which in turn sets off other energetic materials.

Current lots of Al 6061 could not duplicate the double shear breaking load values and so it was attempted to achieve a double shear breaking load with a stable microstructure in the Al 7075 alloy.

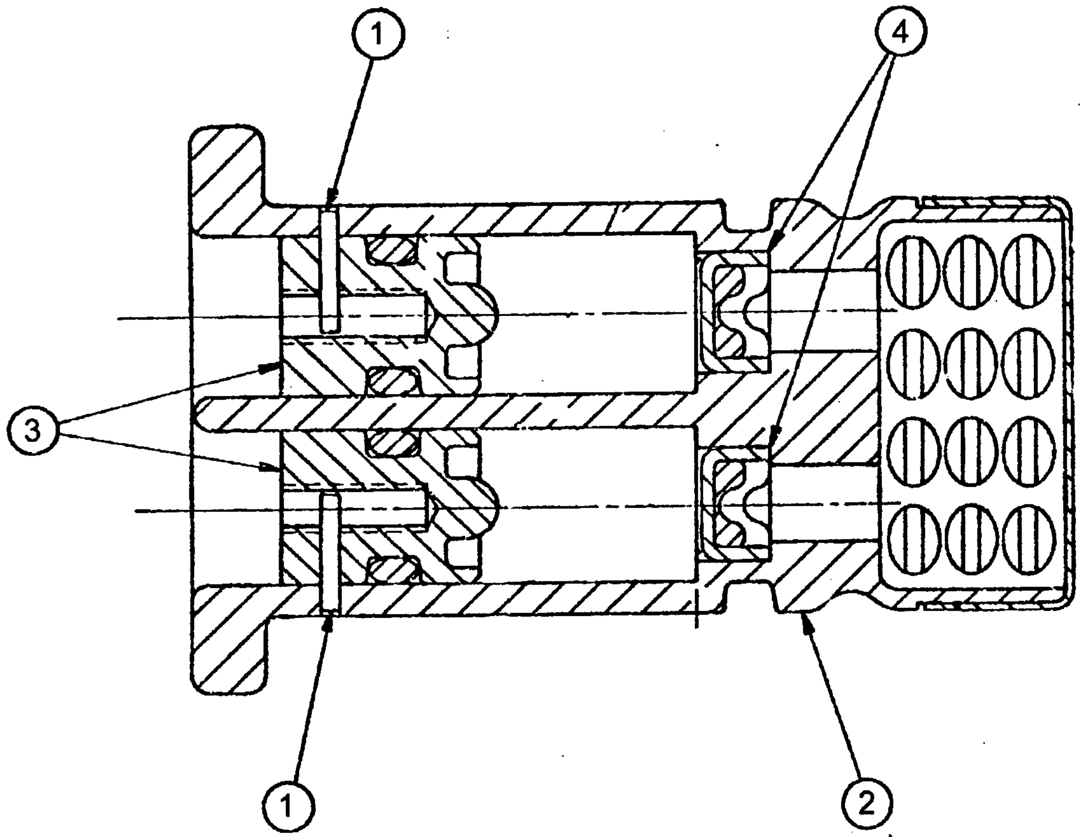


Figure 1. Air crew ejection device.

EXPERIMENTAL PROCEDURES

The material used in this program was 7075-T6 aluminum wire. This wire was drawn to the specified final diameter prior to the T6 heat treatment. The nominal chemical composition of this alloy is 1.2-2.0 Cu, 2.1-2.9 Mg, 0.3 max Mn, 0.4 max Si, 0.5 max Fe, 0.18-0.28 Cr, 5.1 to 6.1 Zn, 0.2 max Ti, 0.05 max others. This is a heat treatable alloy that is usually solution treated between 870 and 900 °F. If left to age at room temperature, the alloy will continue to strengthen throughout its service life. A T6 aging treatment is typically performed at 225 °F until the alloy reaches its maximum strength. For this application, the T6 heat treatment resulted in a higher double shear breaking load than the required range of 46-51 lbs. for the finished diameter. Since very rapid precipitation and growth takes place in this alloy between 750 and 550 °F, heat treating material with the T6 temper at temperatures lower than 870 °F was attempted to coarsen the precipitates and lower the strength.

Another heat treatment that results in lower strength is the overaged T7 heat treatment, which is typically performed in two steps. The first step is performed at 225 °F and the second between 325 and 350 °F. The first step forms a high density of small precipitates. These precipitates produce high strength. During the second step the precipitates coarsen, reducing the strength and providing exfoliation and stress corrosion cracking resistance. This two step heat treatment results in a microstructure that is very stable over time, and a wide range of strengths can be obtained by controlling the time at each temperature.

The heat treatments were performed in a small air furnace. The temperature was controlled by a thermocouple. Three wires, about four inches long, were heat-treated in one lot. Whenever possible the solution treatments were performed at the same time. The aging treatments were also performed together, with the lots being pulled out at their assigned times. The wires were water quenched after the solution treatment but air cooled after all other heat treatments. The heat treatments were selected iteratively with the result of the double shear breaking load tests or hardness tests used to indicate the time and temperature of subsequent heat treatments.

A cross section of each of the three wires in a lot was mounted for hardness measurements. The hardness was measured using diamond pyramid hardness indentor using 200gf load and 14 sec indent time and measured on the Vikers scale according to ASTM E384. Both diagonals of the indentation were measured using a Clemex image analysis system. Three indents were made on each wire cross section. The reported values are the average of these nine measurements.

The shear testing was done according to ASTM B565 94 with a cross head speed of 0.125 in/min. The diameter of the shear pin hole in the test jig was between 0.30 and 0.32 inches. The test was performed on an Instron machine with the full scale load set at 225 lbs. and the data collected electronically. Five tests were performed on one to three wires from each heat treatment lot.

RESULTS

The results of the coarsening heat treatments and the associated hardness and double shear breaking load values are presented in Table 1. The coarsening heat treatments are presented graphically in

Figure 2 through Figure 4. Several heat treatments yielded the required double shear breaking load. However, the time and temperature for the heat treatment would have to be carefully controlled to produce the desired results. It can be seen in

Figure 2 that a fifteen minute heat treatment at 600 °F and 700 °F results in a double shear breaking load that is too low and too high respectively, while heat treatment at 650 °F results in a double shear breaking load in the required range. Heat treating just fifteen more minutes at 650 °F hardens the alloy to the very top of the necessary range.

The time and temperature range to get the required double shear breaking load is narrow, as shown in Figure 4.

Table 1. Coarsening treatments on Al 7075-T6 wire

SAMPLE ID	Hardness HV	Standard Deviation HV	Double Shear Breaking Load lb	Standard Deviation lb	Coarsening Temperature °F	Treatment time hr
CV	125.1	4.5	59.36	0.29	850	0.25
CU	123.1	2.4	58.16	0.25	800	0.25
DA	131.7	5	57.82	-	800	0.5
CT	103.6	2.1	51.90	0.46	750	0.25
CS	100	3.5	51.07	0.12	700	0.25
CA	96.3	2.9	48.98	0.13	650	0.25
CB	97.7	1.5	50.43	0.16	650	0.5
CC	96.2	2.1	50.29	0.20	650	0.75
CD	96.1	2.6	49.96	0.27	650	1
CE	96.9	2.9	50.16	0.16	650	1.5
1	110	3.7	67.22	1.69	650	2
CF	96.7	2.5	49.84	0.31	650	2
2	110	4	68.17	0.39	650	2.5
3	101.9	8.6	68.20	0.73	650	3
CG	86.3	2.2	40.79	0.51	600	0.25
CH	83.1	2	39.27	0.35	600	0.5
CI	79.4	1.7	38.30	0.13	600	0.75
CJ	77.2	1.6	37.73	0.04	600	1
CK	77.3	3.3	39.05	1.18	600	1.5
CL	78.1	1.9	39.26	1.64	600	2
CM	98.4	3.2	45.23	1.37	550	0.25
CN	91.2	2.5	42.28	0.48	550	0.5
CO	88.9	3.2	41.23	0.67	550	0.75
CP	85.8	3.2	40.30	0.66	550	1
CQ	84.1	2.8	38.25	0.45	550	1.5
CR	82.3	1.7	37.36	0.17	550	2
DF	120	2.9	50.52	-	525	0.25
DH	118	3.2	50.93	1.24	525	0.25
DI	115.6	3.9	48.52	1.01	525	0.3
DJ	110.3	3.5	47.03	0.68	525	0.42
DG	106.1	3	45.36	0.56	525	0.5
DK	109.2	1.9	45.66	0.65	525	0.5
CW	134.8	4.1	56.58	0.68	500	0.25
DL	123.1	3.1	49.98	1.28	500	0.25
DM	118	3	49.00	0.65	500	0.3
DN	108.1	6.6	46.68	0.87	500	0.42
DB	99.7	3.2	43.54	0.87	500	0.5
DO	101.8	2.6	46.03	1.10	500	0.5

Table 1 continued.

SAMPLE ID	Hardness HV	Standard Deviation HV	Double Shear Breaking Load Lb	Standard Deviation Lb	Solution Treatment Temperature °F	Treatment time Hr
DD	93.1	2.9	41.31	2.79	500	1
CX	148.4	5.6	59.81	1.18	450	0.25
DC	151.3	3	60.23	0.49	450	0.5
DE	139.2	4.1	57.08	0.67	450	1
DP	133.6	4.5	57.83	2.79	450	1
1DQ	138.2	2.8	55.35	1.18	450	1.25
DR	132.2	4.5	55.06	0.49	450	1.5
DS	129.4	3.8	53.48	0.67	450	1.75
DT	130.3	4.2	52.17	1.45	450	2
CY	171	4.9	70.68	0.12	400	0.25
CZ	167.8	5.9	70.20	0.73	350	0.25

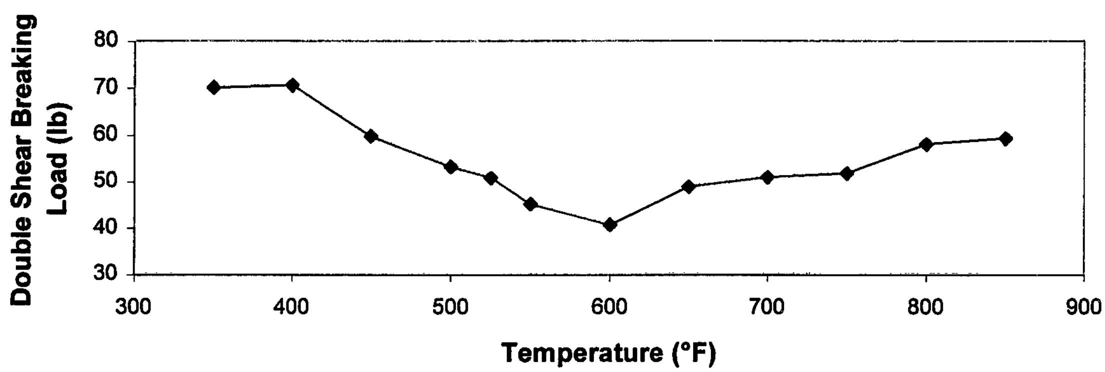


Figure 2. Double shear breaking load after heating 7075 T6 wire for 15 minutes.

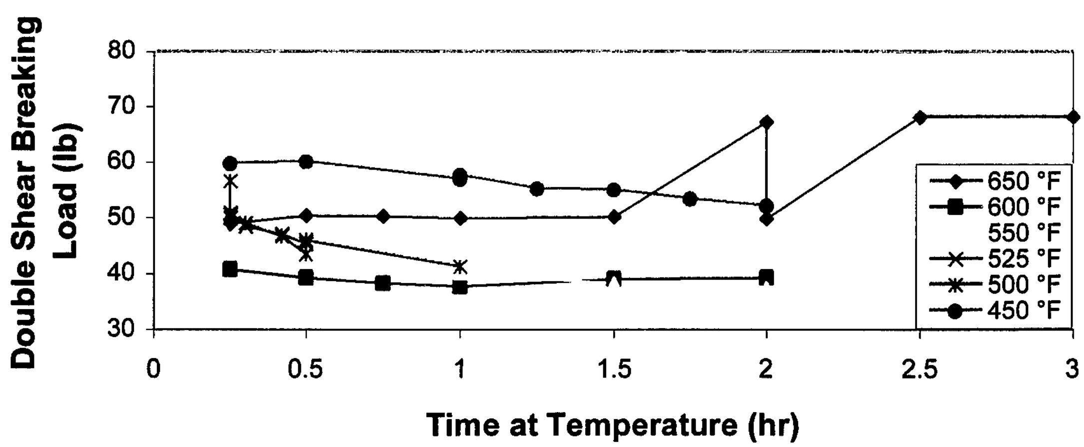
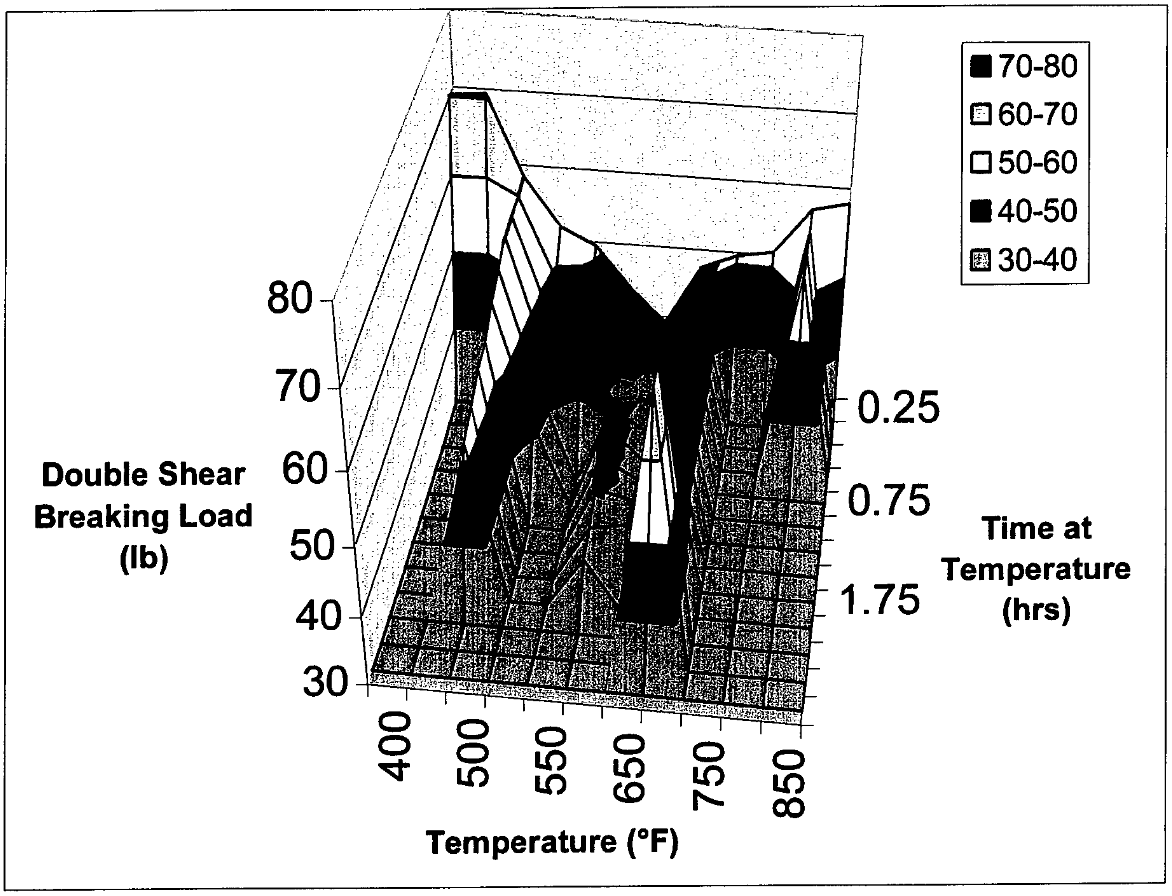


Figure 3. Double shear breaking load after heating 7075 T6 wire at various temperatures.

Figure 4. Double shear breaking load of heat treated 7075 T6 wire as a function of both time and temperature.



The full heat treatments are shown in Table 2. The hardness and double shear breaking load increase with solution treatment time until about 10 hours, as shown in Figure 5, after which they level out. Increasing the time spent aging at 225 °F below one hour increases the subsequent hardness after aging at 325 °F as shown in Figure 6. The double shear breaking load continued to increase over the aging times investigated. All double shear breaking loads were above the target range.

Figure 7 shows the result of various heat treatments after solution treating for 32 hours. The longer the wires were aged at 225 °F the stronger it was. But upon coarsening for 48 hours or more, the wires aged at 225 °F for eight hours were not as strong as the wires aged at 225 °F for one or 72 hours. It wasn't until the wires were aged for 144 hours that they reached the target double shear breaking load range. The wire aged for 168 hours was also in the proper double shear breaking load range. Duplicate samples were heat treated as follows; 32 hours solution treatment, eight hours at 225 °F and 148 hours at 350 °F. The results were again in the same double shear breaking load range. These wires performed successfully in the proof test.

Table 2. Full heat treatments on Al 7075 wire.

Sample ID	Hardness HV	Standard Deviation HV	Double Shear Breaking Load lb	Standard Deviation	Solution Treatment 870-900 °F hr	Aging 225 °F hr	Aging 325 °F hr	Aging 350 °F hr
as received T6	172.2	6.2	73.17	0.36				
as received T6	175.6	6.8	70.38	2.45				
st-wq	152.6	4.9	64.20	0.89	1			
A	147.4	8.1	64.3	2.1	1	0.5		
B	148.3	5.9	65.7	0.5	1	1		
C	160.8	7	60.7	3.8	1	0.5	1	
D	158.2	8.5	65.6	2.5	1	0.5	0.5	
E	155.3	9.6	65.9	3.2	1	0.5	1	
F	156.2	6.6	67.4	1.7	1	0.5	0.5	
G	156.6	7.5	68.3	0.6	1	2		
H	163.7	4.7	69.8	1.0	1	4		
I	179.1	5	71.87	1.35	1	2	1	
J	178.8	4.2	71.30	0.49	1	4	1	
K	173.1	5.6	73.41	1.16	1	2	2	
L	178.9	7.5	71.90	1.42	1	4	2	
M	179.4	5.8	73.61	0.71	1	2	4	
N	181.4	8.1	72.92	0.42	1	4	4	
O	174.3	5.9	71.17	1.18	1	1		1
P	171.2	6.5	68.51	0.51	1	1		0.5
Q	152.4	8.1	62.33	0.5	2			
R	154.9	4.6	63.60	1.3	4			
S	158.2	3.6	64.63	0.48	8			
T	157.2	2.4	63.74	0.74	16			
U	159.2	2	66.10	0.33	32			
V	158.4	2.2	66.17	0.27	64			
AA	168.6	2.1	72.91	0.76	32	8		
AB	172.6	4.2	73.67	0.66	32	16		
AC	181.4	2.8	75.95	0.52	32	32		
AD	184.6	2.6	76.62	0.86	32	64		
AE	177.6	3	71.37	0.41	32	8		2
AF	170.9	1.5	69.04	0.45	32	8	2	
AG	175.1	3.5	67.69	1.49	32	8		4
AH	174.9	4.1	69.83	1.25	32	8		8
AI	169.2	4.7	67.37	0.96	32	8		16
AJ	164.3	2.9	65.42	0.91	32	8		32
AK	150	2.3	61.02	1.11	32	8		64

Table 2 continued.

Sample ID	Hardness HV	Standard Deviation HV	Double Shear Breaking Load lb	Standard Deviation	Solution Treatment 870-900 °F hr	Aging 225 °F hr	Aging 325 °F hr	Aging 350 °F hr
AL	138.3	2.8	55.73	1.76	32	8		48
AM	127	1.7	52.55	1.00	32	8		72
AN	125.8	4.1	52.13	1.81	32	8		96
AO	118.4	2.2	51.37	1.48	32	8		120
AP	118	2.2	47.38	1.10	32	8		144
AQ	118	2.2	48.17	0.84	32	8		168
AR	182.7	4.3	73.52	0.69	32	72		0
AS	184.6	2.7	70.42	0.94	32	72		8
AT	167.2	4.5	67.90	2.09	32	72		24
AU	164.4	3.9	63.45	1.42	32	72		48
AV	161.4	5.4	62.08	1.17	32	72		72
AW	151.9	1.8	62.67	2.48	32	72		96
AX	155.7	12.2	59.86	3.31	32	72		120
AY	139.9	2.4	58.49	1.78	32	72		144
AZ	148.3	5	57.98	1.80	32	72		168
BA	79.93	2.28	66.47	1.67	32	1		0
BB	88	0.51	71.66	0.05	32	1		2
BC	88.11	0.77	70.97	0.13	32	1		4
BD	87.92	0.42	70.07	0.27	32	1		8
BE	87.11	0.52	70.76	0.26	32	1		16
BF	85.32	0.68	67.67	0.17	32	1		32
BG	86.18	0.84	64.19	0.07	32	1		64
BH	84.98	0.85	64.72	0.16	32	1		48
BI	82.66	0.87	60.21	2.04	32	1		72
BK	81.07	0.85	58.12	1.04	32	1		96
BL	78.88	0.85	61.43	0.58	32	1		120
BM	79.56	1.41	62.38	0.93	32	1		144
BN	75.32	1.62	58.97	0.87	32	1		168
DU	139.4	5.1	66.99	0.20	0.5	0		0
DV	127.6	3.1	61.00	1.04	0.5	0		0.5
DW	127.6	5.3	59.69	0.63	0.5	0		1
DX	124.3	6.4	57.13	0.19	0.5	0		2
DY	120.9	4.3	55.77	0.58	0.5	0		4
DZ	121.8	4.7	52.66	0.28	0.5	0		8

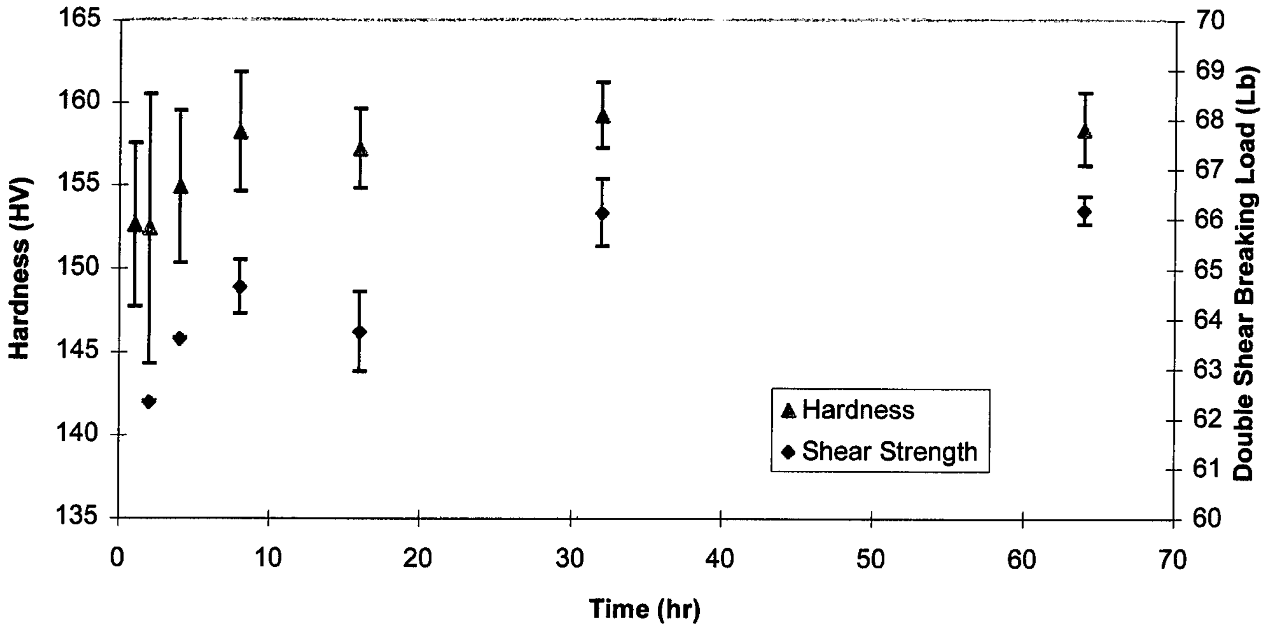


Figure 5. Double shear breaking load and hardness as a function of solution treatment time.

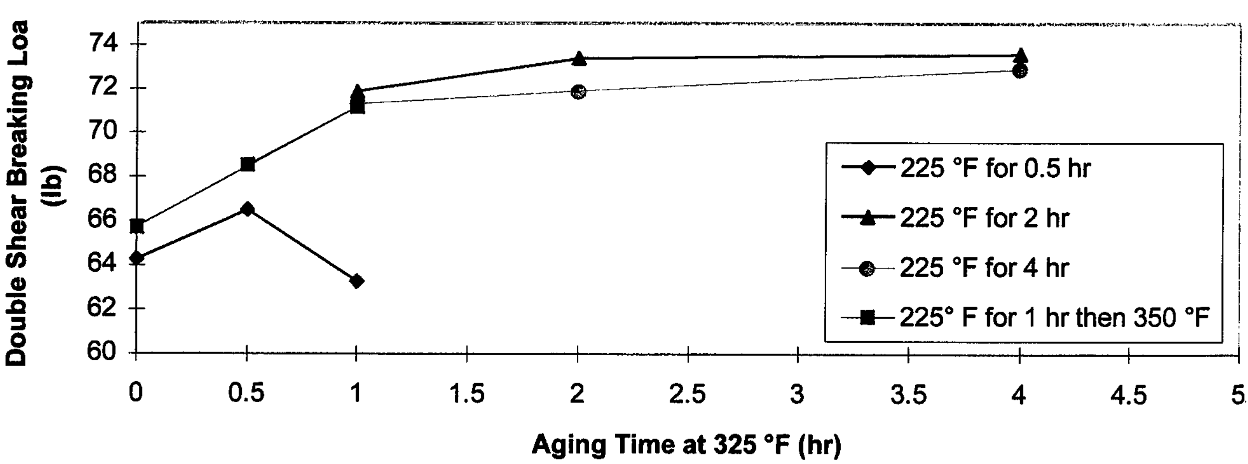


Figure 6. Effect of aging time at 325 °F and 225 °F on double shear breaking load for sample solution treated for one hour.

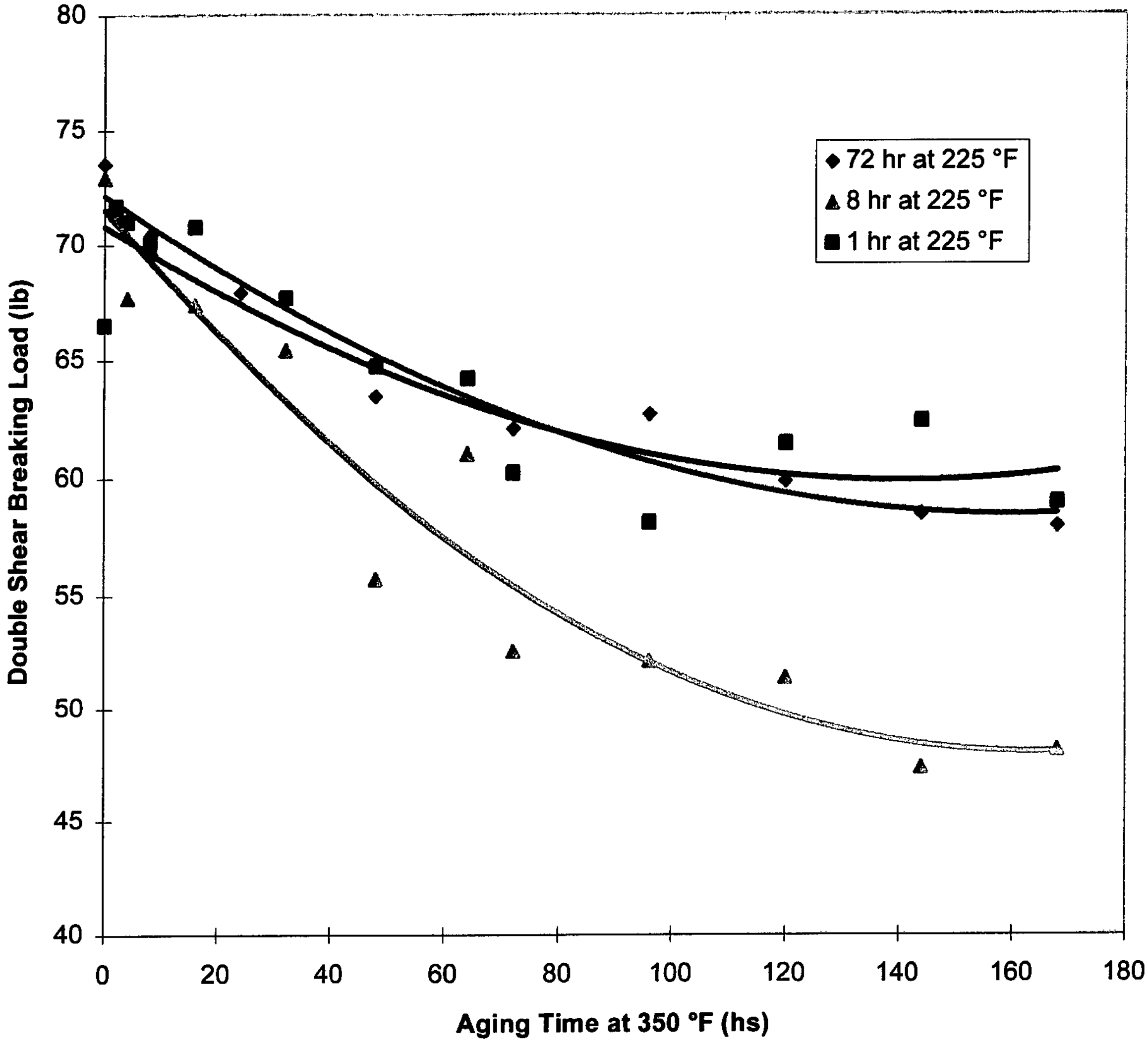


Figure 7. Effect of aging time at 350 °F and 225 °F after solution treatment for 32 hours on double shear breaking load.

During the course of this study it was confirmed that there is a linear relationship between double shear breaking load and hardness as shown in Figure 8. All the data from this study is plotted in Figure 8 except for the data from the wires that were solution treated for 32 hours and aged at 225 °F for one hour. That data showed much lower hardness for a given double shear breaking load.

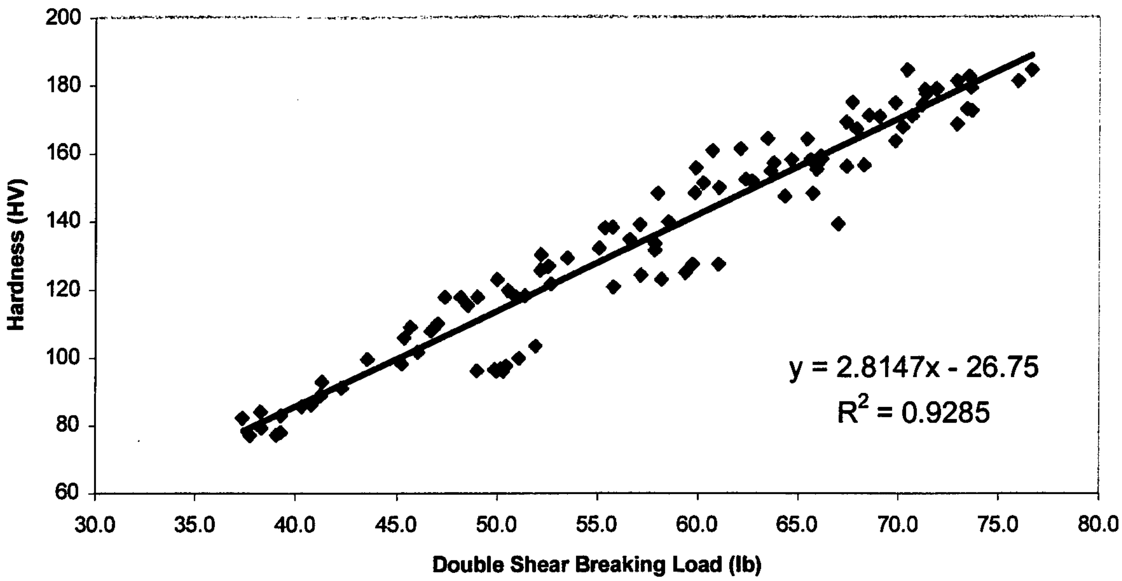


Figure 8. Correspondence between hardness and double shear breaking load.

CONCLUSIONS

Coarsening treatments at 650 °F on the 7075 T6 aluminum resulted in double shear breaking loads in the required range of 46-51 lbs. at the finished diameter of 0.0285-0.0295 in.; however, small changes in time or temperature resulted in large changes in the double shear breaking load.

Solution treating and aging required long times at temperature in order to produce a double shear breaking load low enough to be in the required range.

The heat treatment that was selected was performed on several samples at different times and the material was successfully proof tested. This heat treatment is: solution treatment between 870 and 900 °F for 32 hours, then aged eight hours at 225 °F followed by 148 hours at 350 °F.

A linear relationship between the hardness and double shear breaking load was established.

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